EFFECTS OF DEFOLIATION AND ROOT PRUNING ON THE CHEMICAL COMPOSITION OF SWEET-CORN KERNELS[1]

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INTRODUCTION

Since sweet corn in the fresh and in the canned condition is widely used for human food, it is desirable to know as much as possible of the relation of cultural practices and crop hazards to its composition and quality. In the field the corn plant is often mutilated in various ways; the root system may be injured by the plow or the cultivator; windstorms may throw the plants to the ground; hail may tear the leaves and greatly interfere with their normal functions; and insects may consume more or less of the foliage and injure the stalks. Theoretically, these conditions which directly affect the nutrition and development of the corn plant should affect the composition and quality of the grains. The object of the present work was to determine whether or not such is the case.

LITERATURE

Heckel (*7, 8, 9, 10*),[2] in a series of studies on the effect of emasculation on the sugar content of corn and sorghum, found that in general this treatment resulted at first in an increase in the amount of saccharose, levulose, and dextrose over that of the check plants, followed by a decrease in these sugars. Some variation was noted, however, in the behavior of different varieties. This worker made a study of the possible cumulative effect of traumatism on the sugar content in the progeny of corn detasseled for four successive years. An increase in total saccharose and glucose over that in the control plots was noted, the greatest percentage total increase being obtained from strains previously showing only moderate sweetness and the maximum being attained in 24 days after detasseling. No data were given on the chemical composition of the kernels in any of the work above cited.

Haller and Magness (*6*) investigated the relation of leaf area to the growth and composition of apples, and their work is mentioned here as indicating the importance of the amount of foliage in determining the nature of the crop. Apples grown with a large leaf area were higher in dry weight, sugar, and acids than those with smaller leaf surface, and the quality of the fruit was superior. Ripening took place more promptly.

Dungan (*4*) reported on the influence of plant injury and root-rot diseases on the physical and chemical composition of corn grains. In one series of experiments the stalks and shanks of ears were broken but not severed when the grain was in the milk stage and in another series when the grain was in the soft-dough stage. In other experiments the corn seeds were inoculated with root-rot organisms, and the

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[2] Reference is made by number (italic) to "Literature cited," p. 582.

effect on the composition of the grain of plants derived from this seed was determined. The effect of breaking the stalks and shanks of ears was the same on the yield and composition of the grain as premature harvesting. Breaking the shanks when the ears were in the soft-dough stage caused the greatest chaffiness in the grain. Chemical analyses showed no definite correlation between the apparent starchiness of the kernel and the actual quantity of starch. The percentage of total nitrogen, hemicellulose, and nonhydrolyzable material was distinctly higher in grain from ears produced on broken shanks than in grain from ears produced on sound shanks. The mutilation of the shanks resulted in a lower ether extract and starch content in the grain. Inoculation of the seed at planting time with root-rot organisms resulted in grain of a lower specific gravity than that from the uninoculated seed but no significant differences were noted in the chemical composition of the grain produced. There was slightly more nitrogen in the corn from inoculated seed and a little less ether extract and total sugar.

METHOD OF INVESTIGATION

The variety of corn used in the present investigation was Stowell Evergreen, grown at the Arlington Experiment Farm, Rosslyn, Va., during the season of 1927. The soil was a deep, fertile loam, and the seeding was heavy. When the plants were 8 to 12 inches high they were thinned, vigorous plants being left at 14 to 18 inches in the row. The rows were 3.3 feet apart. The plants used in the investigation were from two plots, one of which was planted on June 22 and the other on June 27. The combined plots, which were contiguous, totaled one-fifth of an acre. They were inspected daily from August 19 to September 10, and, for later identification, the newly forming ears were tagged on the day of the first appearance of silks, as in earlier studies (*2*, *3*, *11*). The plants on which the present report is based, between 400 and 500 in number, silked during the period from August 26 to August 31. They were treated as 10 separate groups, though the individual plants of each group were uniformly distributed within the two plots. The groups were treated as follows:

Group 1.—The leaf at the ear was left and the alternate leaves, both above and below the ear were severed close to the stalk. This was done on the day of silking.

Group 2.—All leaves except the one at the ear were removed on the date of silking.

Group 3.—All leaves were removed five days after silking.

Group 4.—Treated in the same manner as group 3, except that defoliation was performed 10 days after silking.

Group 5.—The leaves were all removed 15 days after silking.

Group 6.—The leaves were all removed 20 days after silking.

Group 7.—The plants were assumed to stand in the center of a square 6 inches on each side, and by means of a sharp spade the roots were cut to a depth of 18 inches on two adjacent sides of the square. It was assumed that one-half the roots were pruned away by this treatment. This was done on the date of silking.

Group 8.—The roots were pruned away to a depth of 18 inches on all four sides of the 6-inch square on the day of silking.

Group 9.—Partial defoliation and partial destruction of roots were performed, half the leaves and half the roots being destroyed on the day of silking.

Group 10.—Entirely normal, representative plants which received the usual cultivation and were not mutilated in any way served as controls.

Pressure of other work prevented a further elaboration of the root-pruning experiments.

None of these plants produced suckers or showed regeneration of leaves following defoliation.

At intervals of 5 days up to 30 days after mutilation, representative samples of 8 to 12 ears were collected where feasible from each group. The ears were taken to the laboratory, husked and silked and the kernels cut from the ear with a sharp knife, close to the cob. The material thus obtained was then thoroughly mixed and duplicate samples of 100 gm. each weighed out, covered at once with 95 per cent alcohol, and heated to boiling to inactivate the enzymes and prevent chemical changes. At the end of the season these samples were analyzed for carbohydrates, following the method of the Association of Official Agricultural Chemists (*1*).

During the period of the experiment the weather conditions were very favorable for corn. There was a sufficiency of rain, with normal summer temperatures and an absence of heavy winds or violent storms that might have injured the plants or interfered with the progress of the experiments.

The size of the ears and the yields of corn were not carefully determined, but a fair estimate was made by comparing the ears and yields of the mutilated plants with those from the normal controls.

EXPERIMENTAL RESULTS

The chemical data obtained from the analysis of samples from the different groups of plants are presented in Table 1, and a statistical analysis of the differences in total solids, total sugars, and acid-hydrolyzable substances between the various test samples and the controls is shown in Table 2. Use here was made of the symbols and formulas employed by Fisher (*5*) in testing the significance of the mean of small samples. In the headings of the various columns, $\bar{y}$ represents the mean of the small sample, s the standard deviation of this sample, and $\frac{P}{2}$ the probability of the value t derived by use of the formula $t=\frac{\bar{y}\sqrt{n'}}{s}$, or similar formula suited to the treatment of allied data, being exceeded in a positive or negative direction only, in other samples from the same universe. In the use of this symbol, only those values of $\frac{P}{2}$ less than 0.050 are considered to indicate significant differences; the smaller the value of $\frac{P}{2}$ the more significant the difference. A brief consideration of the formulas used in the present calculations is to be found in the footnotes to Table 2. The minus and plus signs in the $\bar{y}$ columns show respectively whether the mean of the total solids, total sugar, and acid-hydrolyzable substances of the test corn at different stages of development was less or greater than the mean of the control corn sampled at like stages of development.

TABLE 1.—*Effect of defoliation and root pruning on the chemical composition of the developing grains of Stowell Evergreen sweet corn*

Group No.	Treatment of plants	Age of ears from date of silking	Total solids	Alcoholic extract	Residue	Total sugar	Reducing sugar	Sucrose	Acid-hydrolyzable substances
		Days	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1	Half of leaves removed at time of silking	10	9.67	6.13	3.54	4.24	2.94	1.30	1.45
		15	13.83	8.02	5.81	5.78	2.30	3.48	3.25
		20	18.05	7.62	10.43	4.87	1.49	3.38	8.12
		25	22.46	7.40	15.06	3.98	.96	3.02	12.01
		30	25.97	6.36	19.61	3.43	.62	2.81	16.08
2	Leaves all removed except one at time of silking	10	8.87	5.60	3.27	3.92	2.15	1.77	1.30
		15	11.60	6.60	5.00	3.92	2.09	1.83	2.75
		20	17.79	7.24	10.55	5.16	1.00	4.16	5.80
		25	22.37	7.01	15.36	4.83	.87	3.96	12.60
		30	23.08	6.05	17.03	4.47	.78	3.69	14.13
3	Leaves all removed 5 days after silking	10	9.25	5.84	3.41	3.31	2.50	.81	.79
		15	--------	--------	--------	--------	--------	--------	--------
		20	14.21	6.48	7.73	4.36	1.28	3.08	3.86
		25	22.37	6.81	15.56	4.02	.83	3.19	10.26
		30	--------	--------	--------	--------	--------	--------	--------
4	Leaves all removed 10 days after silking	10	--------	--------	--------	--------	--------	--------	--------
		15	11.80	7.41	4.39	5.02	2.00	3.02	2.56
		20	15.46	6.76	8.70	4.64	1.23	3.41	5.22
		[1] 25	22.90	6.82	16.08	3.70	.75	2.95	11.90
		[2] 25	18.45	5.29	13.16	1.93	.79	1.14	7.96
		[1] 30	26.78	6.40	20.38	3.01	.56	2.45	14.67
		[2] 30	19.45	4.84	14.61	1.79	.55	1.24	9.01
5	Leaves all removed 15 days after silking	10	--------	--------	--------	--------	--------	--------	--------
		15	--------	--------	--------	--------	--------	--------	--------
		20	14.46	6.20	8.26	3.33	1.04	2.29	5.04
		25	21.63	5.48	16.15	2.04	.46	1.58	11.62
		30	25.34	4.91	20.43	1.84	.39	1.45	14.71
6	Leaves all removed 20 days after silking	30	26.92	4.16	22.76	1.88	.47	1.41	16.61
7	Roots pruned on 2 sides at time of silking	10	11.12	7.12	4.00	4.16	2.20	1.96	1.64
		15	15.88	8.56	7.32	5.76	2.07	3.69	4.03
		20	20.52	8.18	12.34	5.04	1.29	3.75	8.74
		25	24.46	7.08	17.38	4.01	1.01	3.00	14.25
		30	27.31	6.54	20.77	3.63	.44	3.19	17.23
8	Roots pruned on 4 sides at time of silking	10	--------	--------	--------	--------	--------	--------	--------
		15	15.78	8.36	7.42	5.73	1.74	3.99	4.08
		20	20.70	8.04	12.66	5.02	1.17	3.85	8.99
		25	27.70	7.84	19.86	4.46	.76	3.70	16.28
		30	31.30	5.88	25.42	3.23	.71	2.52	21.1
9	Half of leaves removed and half of roots cut at time of silking	10	9.63	6.06	3.57	3.25	1.83	1.42	1.43
		15	14.70	8.02	6.68	4.90	1.90	3.00	3.61
		20	18.86	7.80	11.06	4.94	1.01	3.93	7.85
		25	--------	--------	--------	--------	--------	--------	--------
		30	29.45	6.14	23.31	3.02	.58	2.44	19.34
10	No treatment (used as control)	10	9.96	6.00	3.96	4.06	2.88	1.18	1.61
		15	14.44	7.60	6.84	5.76	1.84	3.92	3.76
		20	18.82	7.16	11.66	4.84	1.36	3.48	8.35
		25	23.17	6.72	16.45	4.17	.74	3.43	12.78
		30	25.45	5.94	19.51	3.37	.62	2.75	16.19

[1] Normal grains. [2] Shriveled grains.

TABLE 2.—*Significance of differences in total solids, total sugars, and acid-hydrolyzable substances between corn from defoliated and root-pruned plants and that from untreated controls, as determined by statistical analysis*

[Calculated from the data of Table 1]

Group No.	Total solids			Total sugars			Acid-hydrolyzable substances		
	$\bar{y}$	s	$\frac{P}{2}$	$\bar{y}$	s	$\frac{P}{2}$	$\bar{y}$	s	$\frac{P}{2}$
1	−0.372	0.531	0.097	+0.020	0.134	0.378	−0.356	0.278	0.024
2	−1.626	.915	.009	+.020	1.134	(1)	−1.222	1.052	.032
3	−2.040	2.226	.130	−.460	.300	.063	−2.610	1.836	.072
4	[2] −1.235	2.160	.169	−.443	.227	.017	−1.683	.999	.023
5	−2.003	[3] .564	(4a)	−1.723	.352	.007	−1.983	1.160	.049
6									
7	+1.490	.288	(5)	+.080	.167	.174	+.640	[3] .362	(4c)
8	+3.400	[4] .624	(4b)	+.075	1.953	(1)	+2.362	[3] .728	(4d)
9	+.990	2.019	.199	−.480	.449	.085	+.580	1.720	.275

[1] More than 0.9.
[2] The data given under 4 are based on the results from normal-appearing grains.
[3] In these cases a trend with age was shown, and the data here were calculated from the line of regression. The formulas used were:

$$s=\sqrt{\frac{S(y-Y)^2}{n'-2}} \text{ and } n=n'-2,$$

in which $(y-Y)$ = the deviation of y from the calculated value Y on the line of regression.
a = mean of the y's.
n' = number of items in the small sample.

In all other cases the formulas

$$s^2=\frac{S(y-\bar{y})^2}{n'-1},\ t=\frac{\bar{y}\sqrt{n'}}{s}, \text{ and } n=n'-1 \text{ were used.}$$

[4] In these cases it is not possible to express the significance of the difference between test and control by a single value. (Fisher, *5, pp. 99–123.*) The formulas for the lines of regression are:
(*a*) $y=12.628-0.425\,x$, the range of the x's being 20 to 30 days, inclusive.
(*b*) $y=3.881+0.324\,x$, the range of the x's being 15 to 30 days, inclusive.
(*c*) $y=-.648+0.064\,x$, the range of the x's being 10 to 30 days, inclusive.
(*d*) $y=-5.229+0.337\,x$, the range of the x's being 15 to 30 days, inclusive. In all cases the interval of observation was 5 days.
[5] Less than 0.1.

EFFECT OF PARTIAL AND COMPLETE DEFOLIATION

On the whole, partial defoliation at the time of silking (group 1) made but little difference in the chemical composition of the grain as compared with that from normal plants, though the acid-hydrolyzable substances were definitely lower than in the control corn. In the case of the corn from plants entirely defoliated at the time of silking (group 2) the total solids and the acid-hydrolyzable substances were significantly lower than in the control corn.

The most marked effect of defoliation at this stage of development, as determined by careful observation, was in the size of the ears and in the yields. In the case of the plants from which half of the leaves were removed the ears were only one-half to two-thirds as large as normal ears, and on the ears of the nearly completely defoliated plants the kernels were smaller in size than on normal ears. They appeared to have developed more slowly, but in all other respects seemed normal. There was considerable variation in the behavior of the plants treated in this way at the time of silking. Some produced no seed at all, the ovules failing to develop, while others developed from 50 to 200 grains. The normal plants produced from 350 to 400 kernels to the ear.

The data showing the effect of complete defoliation five days after silking on the chemical composition of the corn (group 3) are incomplete, but so far as they are available they indicate results similar to those where the leaves were removed at the time of silking. The differences between this corn and the controls, however, were less significant, though more complete data might have shown more marked effects of this treatment. Inspection of the ears tof his group showed that some kernels started to develop and subsequently failed. They had developed sufficiently, however, to be included in the sample, and although they formed but a relatively small percentage of the total sample, their effect on the composition was perceptible.

Defoliation 10 days after silking (group 4) resulted in marked physical and chemical differences in the grains. The ears from this defoliated corn sampled 15 and 20 days after silking showed some kernels that seemed to be developing normally and others that had failed completely to develop. In the corn sampled 25 and 30 days after silking the differences were so marked that two sets of samples were taken, one of the normal-appearing kernels and another of the shriveled grains. Differences in the chemical composition of these two sets of samples are shown in Table 1. The "normal" kernels had approximately the same composition as those from the plants defoliated at the time of silking. The sugar and the acid-hydrolyzable substances were significantly lower than in the kernels of the control corn. In the shriveled grains, on the other hand, the total solids and the sugar and acid-hydrolyzable substances were much lower than in the control samples. It is apparent that the incoming storage material, in the case of the ears of this lot, was insufficient to meet all needs, and a part of the kernels received it all, the remaining being left to wither.

Cessation of development did not occur at exactly the same time in all kernels that failed to mature properly; consequently, in the later stages of development the ears showed fewer normal grains than those harvested earlier. There was, of course, considerable variation in the behavior of individual plants. A small percentage of ears was found on which all the kernels appeared to have stopped developing at the same time. In such cases the plant as a whole ceased to function and usually withered and died prematurely.

The corn from plants defoliated 15 days after silking and sampled after 20, 25, and 30 days (group 5) was characterized by a significantly lower content of sugar and acid-hydrolyzable substances than the control corn.

The single sample from corn defoliated 20 days after silking and sampled 30 days later (group 6) showed higher total solids, lower sugar content, and slightly higher content of acid-hydrolyzable substances than the corn from the control plants. It is probable that these differences were due, in part at least, to the drying out of the corn prior to sampling. The data are too few, however, to warrant definite conclusions on this point.

The ears of this lot showed again the unequal development of the grains. Differences in development could not be discerned as soon after defoliation, however, as in the corn mutilated at or shortly after the silking time. There was also a larger percentage of ears on which grains failed to continue development.

EFFECT OF ROOT PRUNING

The total solids and the acid-hydrolyzable substances of the corn from which half the roots were removed (group 7) were significantly higher than those of the control corn. The differences in total sugar content were not significant. The removal of the roots from the four sides of the 6-inch square (group 8) yielded effects of the same nature, but the figures were more striking. The outstanding results of root pruning were a higher content of total solids and acid-hydrolyzable substances than that of the control corn, whereas lower total solids and a lower content of acid-hydrolyzable substances characterized the defoliated corn. The signs of the data in the $\bar{y}$ columns of Table 2 indicate this clearly.

The removal of half the roots and half the leaves from the same plants (group 9) gave analytical results similar to those of group 8, but the size of the ears in this case was much reduced. The differences between the corn from these plants and that from the controls were not significant.

As indicated by the size of ears, reduction in yields of the root-pruned corn was marked, particularly in the case of those plants which were more severely treated; but the reduction was not so great as that resulting from defoliation.

GENERAL DISCUSSION

In considering the foregoing data it must be borne in mind that the nature and degree of the response of the corn plants to the different treatments was not, from the standpoint of the individual plants, always constant or consistent. Considerable variation in the behavior of individual plants was encountered. So far as the conditions of the experiment permitted, however, the data presented represent the group response.

In these experiments the effects of mutilation of the plant on the chemical composition of the grain were most clearly exhibited in those lots treated 10 and 15 days after silking. In the case of these plants mutilated when the kernels were in an earlier stage of development, the kernels that later failed to grow withered away before significant size was attained, and hence had no significant effect on the character of the sample. Those plants mutilated when the grains were more than 15 days of age yielded corn more closely approaching normal grain according as the treatment was longer and longer delayed.

In considering these data the climatic conditions under which the corn was grown should be held in mind. During the course of the experiments temperature and moisture conditions were very favorable for the growth and maturing of the corn. If hot winds had prevailed at any period subsequent to mutilation, the failure of kernels resulting from root pruning at least would have been greater, and higher total solids of the grain would doubtless have resulted in the case of the defoliated plants.

Yields, as shown by the size of the ears and the number of kernels, were most severely affected when the plants were defoliated at the time of silking. Partial defoliation was found to be much more disastrous to yields than partial root pruning.

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In an earlier publication (*3*) it has been shown that quality in sweet corn is dependent on tenderness of kernel hull, the nature of the polysaccharides present, the sugar content, and other factors. Any condition exerting an unfavorable influence on the uniform composition and quality of the properly harvested corn therefore must of necessity be taken into careful consideration. From these experiments it would appear that, from the standpoint of quality of the canned product, hailstorms or other agencies destroying the foliage would be most severely felt if they occurred from 10 days to 2 weeks after the corn had flowered. The same would probably be true of drought or other unfavorable seasonal conditions.

SUMMARY

Partial or nearly complete defoliation of corn plants at the time of silking caused only small differences in the chemical composition of the developing grains. It decreased the total solids somewhat and seemed to slow down slightly the rate at which the grains matured. Root pruning done at this time resulted in corn of high total solids, and the rate of maturing seemed to be slightly increased. Mutilations at this time tremendously decreased yields, as shown by the small size of the ears and the small number of kernels. Under the conditions of these experiments defoliation was more disastrous than root pruning.

Defoliation performed after development of the kernels was well underway resulted in a very marked change in the chemical composition of the grain. The effects were most severely felt when the plants were defoliated 10 and 15 days after silking, under the climatic conditions prevailing during the period of the experiment. Yields, as indicated by the size of ears and the number of kernels, were also severely reduced under these conditions, but less severely than when defoliation was performed at the time of silking. Beyond the 15-day stage the undesirable consequences of defoliation were progressively lessened as the treatment was delayed.

When the corn plant was mutilated there was a marked difference in the behavior of the grains. Some kernels developed normally, while others on the same ear entirely failed to develop. It appeared that when the organic nutrients were insufficient for all the supply was unequally distributed, a few grains receiving all.

From a consideration of the analytical data it is concluded that any condition affecting the vegetable development of the plant adversely would affect the quality of the canned product most unfavorably if it became operative 10 to 15 days after the silking of the corn.

LITERATURE CITED

(1) ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS.
1920. OFFICIAL AND TENTATIVE METHODS OF ANALYSIS . . . AS COMPILED BY THE COMMITTEE ON REVISION OF METHODS. REVISED TO NOVEMBER 1, 1919. 417 p., illus. Washington, D. C.

(2) CULPEPPER, C. W., and MAGOON, C. A.
1924. STUDIES UPON THE RELATIVE MERITS OF SWEET CORN VARIETIES FOR CANNING PURPOSES AND THE RELATION OF MATURITY OF CORN TO THE QUALITY OF THE CANNED PRODUCT. Jour. Agr. Research 28: 403–443, illus.

(3) ——— and MAGOON, C. A.
1927. A STUDY OF THE FACTORS DETERMINING QUALITY IN SWEET CORN. Jour. Agr. Research 34: 413–433, illus.

(4) DUNGAN, G. H.
1926. THE INFLUENCE OF PLANT INJURY AND THE ROOT-ROT DISEASES UPON THE PHYSICAL AND CHEMICAL COMPOSITION OF CORN GRAIN. Ill. Agr. Expt. Sta. Bul. 284, p. 255–281, illus.

(5) FISHER, R. A.
1928. STATISTICAL METHODS FOR RESEARCH WORKERS. Ed. 2, rev. and enl., 269 p., illus. Edinburgh.

(6) HALLER, M. H., and MAGNESS, J. R.
1926. THE RELATION OF LEAF AREA TO THE GROWTH AND COMPOSITION OF APPLES. Amer. Soc. Hort. Sci. Proc. 22: 189–196.

(7) HECKEL, E.
1912. DE L'INFLUENCE DE LA CASTRATION MÂLE, FEMELLE ET TOTALE SUR LA FORMATION DU SUCRE DANS LES TIGES DE MAÏS ET DE SORGHO SUCRÉ. Compt. Rend. Acad. Sci. [Paris] 155: 686–690.

(8) ———
1914. SUR LA CASTRATION MÂLE DU MAÏS GÉANT DE SERBIE. Compt. Rend. Acad. Sci. [Paris] 159: 595–597.

(9) ———
1915. CRÉATION D'UNE RACE NOUVELLE DE MAÏS GÉANT À TIGE SUCRÉE. Compt. Rend Acad. Agr. France 1: 551–554.

(10) ———
1915. SUR LA TRANSMISSION PAR GRAINES DES EFFETS DE LA CASTRATION DANS LES TIGES DE MAÏS. Compt. Rend. Acad. Sci. [Paris] 161: 338–340.

(11) MAGOON, C. A., and CULPEPPER, C. W.
1926. THE RELATION OF SEASONAL FACTORS TO QUALITY IN SWEET CORN. Jour. Agr. Research 33: 1043–1072, illus.

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